International Journal of Plant Production 2 (2), April 2008
ISSN: 1735-6814 (Print), 1735-8043 (Online)
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Response of tomato to irrigation with saline water applied by different irrigation methods and water management stratigies

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Accepted 6 Nov. 2007; Published online 10 Feb. 2008

Abstract

In a field experiment the effects of irrigation with saline drainage water (seasonal average of 4.5 dS/m) and non-saline water (0.55 dS/m) applied by two different water management strategies (cyclic or blended saline water with non-saline water in different ratios) and two different irrigation methods (drip or furrow) were studied on growth and productivity of tomato (*Lycopersicon esculentum Mill* cv Floradade), salinity distribution in root zone and water use efficiency. The results indicated that salinity (at 3 dS/m and above) significantly reduced leaf area, height and dry weight of plant as well as fruit weight and number and hence total yield, but increased fruit T.S.S. content. Water use efficiency (WUE) was increased by using water with low and moderate salinity levels (2 and 3 dS/m) as compared to those obtained with non-saline water (0.55 dS/m) or the highest salinity level (4.5 dS/m). Salinity increased Na, Cl and Mg contents as well as dry matter percentage, but decreased N, P, K and Ca contents in leaves of plants. Drip irrigation enhanced tomato growth, yield and WUE under both saline and non-saline conditions, but showed more advantages under saline conditions as compared with furrow irrigation. Drip irrigation method did not allow salt accumulation in root zone (wetted area beneath the emitters and the plants). However, more salt accumulated in root zone (30 cm apart from irrigation source) of furrow irrigated plants. Mixing saline with non saline waters (blending) produced better results in terms of more vigorous vegetative growth and highest yield, than that produced by alternate saline with non saline water (cyclic). Using saline water up to 3 dS/m produced yield that was not significantly differ than that produced by non saline water if applied by drip irrigation and blended water management.

Keywords: Irrigation with saline water; Irrigation method; Water management strategies; Salinity distribution; Leaf mineral content; Growth of tomato plants

Introduction

Tomato, *Lycopersicon esculentum* Mill., is one of the most leading vegetebles in economic importance throughout the world including Egypt. Tomato acreage in Egypt was about 150,000 hectar either cultivated in open field or under greenhouse. Most of produced fruits are consumed as a fresh market, but some used for processing.

Irrigation requires relatively large quantities of water which is becoming increasingly scarce. On the other hand, waters of a wide range of quality can be used for irrigation by appropriately selecting crops, irrigation methods and management practices. Non-conventional water resources such as saline drainage water, brackish groundwater and treated wastewater are alternatives to fresh water resources (Rhodes et al., 1988; Grattan et al., 1994; Malash et al., 2005). However, careful management is required to safeguard the environment.

In regions where water resources are limited and the cost of fresh water is prohibitive, crops of moderate to high salt tolerance can be irrigated with saline water especially at later growth stages. The irrigation water can be a mixture of saline with fresh water (blending). Saline water can also be applied in cycles with fresh water. The use of saline drainage water for irrigation has an environmental advantage. It reduces the fresh water requirement for salt-tolerant crops and it decreases the volume of drainage water requiring disposal or treatment.

Drip irrigation, provides a greater advantage in using saline water (Ragab et al., 1984). The system maintains high matric potential and low salt accumulation in the wetting zone, so maintaining a low salinity level in the root zone. In furrow irrigation, salts tend to accumulate in the seed beds (Singh Saggu and Kaushal, 1991) because leaching occurs primarily below the furrows.

The objective of this work was to determine the potential and sustainable use of low water quality (saline drainage water) for irrigation by using different irrigation methods (drip and furrow), water salinities and modality of water application [blending and alternate (cyclic)] of water with different salinities.

Materials and Methods

The experiments were conducted in fields of the Agricultural Experimental Station of the Faculty of Agriculture of Minufiya University in Shibin El-Kom, Egypt (approx. latitude 30.5 N and longitude 31.3 E). The average temperatures in the area during the growing season (5 months; from March to July) were 30.6°C as a maximum and 16.0°C as a minimum (average of 3 years; 2000, 2001 and 2002); there was no rainfall during the period over which the experiments were conducted. The physical (A) and chemical (B) properties of the site of the experiment are shown in Tables 1 (A and B).

Seeds of tomato (*Lycopersicon esculentum* Mill. cv. Floradade) were sown on 15th January in 2000 season and on 11st of January in both 2001 and 2002 seasons, in seed-beds in a plastic house (to protect seedlings from cold weather at this time). After hardening, seedlings were transplanted to field plots[1] consisting of five rows 6 m long on 14th, 10th and 16th of March in the 2000, 2001 and 2002, respectively. Planting spacing were 0.3 m within rows for the three years, and spacing between rows were 1 m in 2000 and 1.2 m in both 2001 and 2002. The distance between any two adjacent plots was not less than 1.5 m.

1- The word 'plot' is used in this study to describe the experimental unit which is a 'sub-sub plot' in terms of the experimental design.

Table 1. Physical (A) and chemical (B) properties of the field soil.
1. (A) Physical properties

Depth (cm)	$CaCO_3$ (%)	Organic matter (%)	Size particle distribution (%)				Texture
			Coarse Sand	Fine Sand	Silt	Clay	
0-30	3.3	2.15	2.58	25.2	41.3	30.9	Clay loam
30-60	2.0	0.70	3.16	26.9	31.1	38.9	Clay loam
60-90	2.2	0.33	3.10	24.3	33.7	38.9	Clay loam
90-120	2.0	---	2.39	27.5	33.8	36.4	Clay loam
120-150	1.6	---	1.93	25.1	39.1	33.9	Clay loam
150-180	1.8	---	1.20	31.1	28.7	39.1	Clay loam

1. (B) Chemical properties

Depth (cm)	pH	EC (dS/m)	Exchangeable Na^+ (meq/100g)	ESP	Soluble ions (meq/100g soil)							
					Ca^{2+}	Mg^{2+}	Na^+	K^+	CO_3^{-2}	HCO_3^-	Cl^-	SO_4^{-2}
0-30	7.80	0.30	0.71	2.82	0.66	0.36	1.59	0.35	0.00	1.00	1.25	0.71
30-60	7.82	0.28	1.33	4.19	0.45	0.30	1.80	0.21	0.00	1.00	1.05	0.71
60-90	7.92	0.32	1.33	4.22	0.32	0.40	2.21	0.17	0.00	1.50	0.85	0.80
90-120	7.95	0.29	1.37	6.37	0.20	0.40	2.30	0.01	0.00	2.00	0.50	0.41
120-150	8.01	0.28	2.08	8.29	0.20	0.32	2.30	0.01	0.00	2.00	0.68	0.06
150-180	8.06	0.28	2.16	8.21	0.25	0.26	2.21	0.02	0.00	1.65	1.00	0.09

Cultural practices such as pest control, harrowing and fertilization were carried out when needed following the guidelines of the Ministry of Agriculture in Egypt. The rates of fertilizer application per faddan[1] were: 120 kg N, 60 kg P_2O_5 and 100 kg K_2O.

Two irrigation methods (i.e., drip and furrow) were used. The drip irrigation system was of similar design to that used in fields by commercial growers in Egypt (using 16mm tubes, with drippers delivering 4L/h set 30cm apart). For the furrow system, the irrigation water was delivered to furrows in the plots by tubes (PVC, 16 mm internal diameter) with 6L/min rate. Furrows were about 20 cm deep and 40 cm wide. Water delivering tubes extended in the middle of the furrows between two adjacent rows. The irrigation water for both systems came from three large storage tanks. One was filled with saline drainage water (4.2- 4.8 dS/m), the second with fresh water (0.55 dS/m) and the third was used for mixing. The chemical analysis and nutrient elements in irrigation water are shown in Tables 2, A&B respectively.

Two water management strategies were used: blended or cyclic. Either saline (4.2-4.8 dSm^{-1}) or fresh (0.55 dSm^{-1}) water were mixed (blended treatment) or fresh and saline water was applied alternatively (cyclic treatment) as shown in Table 3.

A, split split plot design with 3 replicates was used. The irrigation systems were assigned to the main plot, water management strategies to sub-plots and fresh and saline water ratios (salinity levels) to sub-sub plots. The experimental design was carried out according to the method described by Snedecor (1956). Data were analyzed using least significant difference (Steel and Torrie, 1981).

1- faddan = 4200 m^2

Table 2. A: Chemical analysis of irrigation water.

Irrigation water	Ph	EC dS/m	Soluble ions meq/L							
			Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{-}	HCO_3^{-}	Cl^{-}	SO_4^{--}
Fresh water	7.80	0.54	1.56	2.19	3.40	0.15	0.00	2.38	4.40	0.52
Drainage water	8.32	4.60	6.00	4.2	31.55	0.17	0.00	10.50	20.72	10.70

Table 2. B: Nutrient elements in fresh and drainage water used in irrigation.

Water source	Nutrients elements (ppm)					
	N	P	K	Fe	Zn	Mn
Fresh water	3.20	0.21	7.25	0.12	0.17	0.03
Drainage water	25.80	0.48	10.93	0.23	1.20	0.30

Table 3. Saline water ratios and water management stratigies used in this study.

Treatment	Blended	Cyclic	Salinity of irrigation water (Seasonal average)
1	100% fresh water	All irrigations with fresh water	0.55 dS/m
2	60% fresh and 40% saline water	60% of irrigations with fresh water and 40% with saline water	2.0 dS/m
3	40% fresh and 60% saline water	40% of irrigations with fresh water and 60% with saline water	3.0 dS/m
4	100% saline	All irrigations with saline water	4.5 dS/m

Once the plants became well established (40 days after transplanting) the treatments were applied. Three (in 2000 and 2001) or four (in 2002) UPVC tubes (175 cm long, 3.7 cm width and 3.7 mm thick) of a neutron probe (CPN, 50 mCi) were installed in the soil at intervals of 30 cm (in 2000 and 2001) or 10 cm (in 2002) from the irrigation source for estimating soil moisture content vertically and horizontally. Vertical measurements were made periodically at 0-20, 20-40, 40-60, 60-90 and 90-120 cm depth. Irrigation applied when the available soil moisture (ASM) reached 70±3% and sufficient water was added to return the soil moisture to field capacity. The ASM was the difference between field capacity (determined at 0.33 atm) and permanent williting point (determined at 15 atm). ASM was determined in a layer between the soil surface till 60 cm depth and at 20 cm intervals. Measurements were carried out at 2 days intervals. The amounts and dates of irrigation were determined in the light of such measurements. The amount of water applied was determined by using a normal water counter. The number of drip irrigations was almost doubles that of furrow irrigations. On average the volumes of water applied to irrigation were 1300 L and 500 L/plot in furrow and drip irrigation systems respectively. As irrigation occurred when the available soil moisture reached 70±3%, irrigation number varied between treatments (fresh water-irrigated plots need more irrigations than saline-irrigated ones).

The site of the experiment was well drained by using an artificial cover drainage system.

Soil salinity was measured by using salinity sensors (Soil moisture Equipment Corp, Cat No. 5000-A) and a salinity bridge (Soilmoisture Equipment Corp, Cat. No. 5500). Salinity sensors were inserted in the soil at depths of 15, 30, 60 or 90 cm and vertically at 0, 30 or 60 cm intervals from water source in 2001. Measurements of soil salinity shown in this work (Figure 1) were carried out before irrigation applied at 29/6/2001.

The location of plants in this experiment were at 0 and 30 cm apart from the irrigation source in drip irrigation and furrow irrigation, respectively as usually followed in tomato growing.

Plant samples were taken at different growth stages: at 57, 75 and 95 days after transplanting in 2000 season and at 60, 75 and 90 days in the 2001 season and at 60, 70, 80 and 90 days in the 2002 season. Each sample consisted of three plants picked from outer rows of each plot (leaving the 3 inner rows for yield determination). Leaf area/plant, plant height and fresh and dry weight of plants were all determined. Dry weights were measured 48h after placing fresh samples in an oven at 105°C (previously established that the samples had reached constant weight). Relative growth rate (RGR) which is dry weight accumulated per unit of plant dry weight per unit of time ($RGR=\log_e W_2 - \log_e W_1/t_2 - t_1$) was also determined. Leaf mineral contents were measured in dried powdered material. Nitrogen was determined by the micro-Kjeldahl method as described by Peach and Tracey (1956), phosphorus was determined by Frie et al. (1964) method and potassium and sodium were assayed spectrophotometrically according to Johanson and Ulrichs (1959) method using a flame photometer (Corning 400). Calcium and magnesium were determined by titration with versinate (Page et al., 1982). Chloride was determined using titration of silver nitrate solution using potassium chromate as indicator (Page et al., 1982).

Ripe fruits were harvested 2-3 times per week and at the end of the harvesting season, total fruit yield, total fruit number and average fruit weight were all determined. Fruit total soluble solids (TSS) content were determined, by using an abbé hand-held refractometer, in 4 fruit samples (each sample contained 5 fruits from each treatment) taken for four sampling dates throughout the harvesting season.

Results and Discussion

Plant Growth

Irrigation with non-saline water (0.55 dS/m), drip irrigation and blended water management showed higher values of leaf area, height and dry weight of plants than those irrigated with saline water, furrow irrigation and treated by cyclic water management (Table 4).

The highest salinity level reduced leaf area, plant height and plant dry weight by 14.8, 9.0 and 13.8% respectively (relative to those of non- saline water) when drip irrigation was used, however the reduction were (in the same order) 21.0, 10.0 and 17.2% (average of the two seasons) when furrow irrigation was used. The most severe reduction in leaf area by saline water in particular, suggests that leaf area may be the most sensitive vegetative growth character to salinity. Similarly, Li and Stanghellini (2001) reported that the most evident EC effect was a reduction in leaf expansion. Not only leaf expansion was reduced but also number of leaves reduced by salinity (Romero Aranda et al., 2001). In this respect plants that irrigated with saline water (4.5 dS/m) devoted less dry matter to leaves but more dry matter to stems than those irrigated with fresh water (Table 5).

A reduction in leaf area of tomato plants irrigated with saline water was also recorded by Romero- Aranda et al. (2001) who noted that saline water also reduced water uptake, stomatal density, transpiration and net CO_2 assimilation. Also, the reduction in leaf area reduced light interception and thus dry matter produced (Alarcon et al., 1994, Li and Stanghellini, 2001 and Kutuk et al., 2004). Therefore plant dry weight (Table 4) decreased gradually as salinity of irrigation water increased but the reduction was significant only at 3 dS/m and above. Similar trend was also observed with leaf area and plant height with increasing salinity (Table 4).

Drip irrigation increased plant growth in terms of leaf area, plant height and weight as compared to furrow irrigation, with all salinity levels and water managements (Table 4). As compared to furrow irrigation, drip irrigation method enhanced dry matter allocated to leaves and fruits at the expense of dry matter devoted to stems (Table 5), even though, plant height still greater with drip method (Table 4). Similar results were obtained by Bark *et al.* (1979) who reported that drip irrigation caused highest rates of watermelon vegetative growth than sprinkler and furrow irrigation.

As mentioned above plant growth parameters were less affected when saline water was applied through drippers as compared with its application through furrows. This suggests that drip irrigation is preferable when saline water has to be used in irrigation. Similarly, Yadav and Paliwal (1990) recommended drip irrigation method for saline water.

Using blended water management resulted in better growth in terms of higher values of growth parameters (Table 4) than those obtained when cyclic water management was used, at the same salinity level and irrigation method. Moreover, the slight (not significant) increase in values of plant growth parameters when fresh and saline water was blended (up to 2 dS/m), than that received fresh water, was likely due to the relatively high N concentration in drainage water (Table, 2,B) which reached about eight times those found in well and canal (fresh) water. Meanwhile, salinity level of irrigation water i.e., 2 dS/m was not high enough to cause a deleterious effect on growth. Tomato has been reported tolerant to salinity up to 2 dS/m (Yadav and Paliwal, 1990) or even 3 dS/m applied by drip irrigation method (Singh et al., 1978).

Applied saline water in alternate with fresh water (cyclic water management) gave less vegetative growth, than did mixing both waters together (blended water management) (Table 4), perhaps due to the fluctuating soil conductivity which followed the application of saline or fresh water in saline treatments, this conclusion was reported by Malash et al. (in press). Table 5 show that top/root ratio was higher in plants irrigated by drip method than that irrigated by furrows.

RGR measured in 2001 and 2002 seasons was significantly higher early in the season (60-75 and 60-70 days after transplanting, respectively) in plants irrigated by drip irrigation, than those furrow irrigated, however at 75-90 and 80-90 days after transplanting (in the two years respectively) a reverse trend was observed (Table 6). At 70 - 80 days after transplanting (in 2002) no significant differences in RGR values were detected between plants either irrigated by furrows or by drippers. This may suggests that drip irrigation enhanced plant growth early while furrow irrigation activates growth latter in the season.

Table 4. Effect of irrigation method, water management strategy, salinity level and their interaction on some growth parameters at 75 and 70 days from transplanting in 2001 and 2002 seasons, respectively.

Variables		Salinity levels (dS/m)	Leaf area /plant (m^2) 2001	Leaf area /plant (m^2) 2002	Plant height (cm) 2001	Plant height (cm) 2002	Plant dry weight (g) 2001	Plant dry weight (g) 2002
Drip	Cyclic	0.55	1.09	1.27	92.0	88.9	179.4	146.5
		2.00	1.04	1.21	89.0	85.6	167.3	140.9
		3.00	0.97	1.14	87.5	82.2	164.2	131.2
		4.50	0.90	1.11	84.7	79.4	153.7	127.3
		Mean	1.00	1.18	88.3	84.0	166.1	136.5
	Blended	0.55	1.09	1.27	92.0	88.9	179.4	146.5
		2.00	1.12	1.29	93.4	88.1	187.4	149.9
		3.00	1.07	1.24	89.5	84.1	179.4	139.5
		4.50	0.90	1.11	84.7	79.4	153.7	127.3
		Mean	1.05	1.23	89.9	85.13	175.0	140.8
	Average (A)		1.03	1.21	89.1	84.6	170.6	138.7
Furrow	Cyclic	0.55	0.90	1.11	83.5	80.4	143.4	124.0
		2.00	0.89	1.10	81.4	77.8	133.3	114.5
		3.00	0.84	1.02	79.2	75.3	129.6	107.1
		4.50	0.72	0.87	73.8	73.7	122.3	99.1
		Mean	0.84	1.03	79.5	76.8	132.2	111.2
	Blended	0.55	0.90	1.11	83.5	80.4	143.4	124.0
		2.00	0.92	1.13	84.3	81.8	145.6	126.7
		3.00	0.84	1.04	82.4	77.0	136.9	115.5
		4.50	0.72	0.87	73.8	73.7	122.3	99.1
		Mean	0.85	1.04	81.0	78.2	137.1	116.3
	Average (A)		0.85	1.04	80.3	77.5	134.6	113.8
Irrigation water management	Cyclic	2.00	0.97	1.16	85.2	81.7	150.3	127.7
	Cyclic	3.00	0.91	1.08	83.4	78.8	146.9	119.2
	Average (B)		0.94	1.12	84.3	80.3	148.6	123.5
	Blended	2.00	1.02	1.21	88.9	84.9	166.5	138.3
	Blended	3.00	0.96	1.09	86.0	80.6	158.2	127.5
	Average (B)		0.99	1.15	87.4	82.8	162.4	132.9
Salinity levels	Average (C)	0.55	1.00	1.19	87.8	84.7	161.4	135.3
		2.0	0.99	1.18	87.0	83.3	158.4	133.0
		3.0	0.93	1.11	84.7	79.7	152.5	123.3
		4.5	0.81	0.99	79.3	76.6	138.0	113.2
LSD for averages of irrigation methods (A) at P = 0.05			0.12	0.04	5.0	4.3	4.1	4.2
LSD for averages of water management (B) at P = 0.05			0.04	0.01	1.6	1.3	4.4	4.2
LSD for averages of salinity levels (C) at P = 0.05			0.13	0.05	3.0	2.6	4.1	4.7
LSD for interaction (AxBxC) at P= 0.05			0.15	0.16	4.7	5.4	7.6	7.7

In general, RGR values (in 2002) were relatively high between 60-70 days after transplanting, decreased between 70-80 days and then increased again beyond 80 days after transplanting.

Growth and developmental stages in tomato plants are overlapping i.e., plants produce flowers and fruit set while vegetative growth is continuing, all at the same time. However, one can distinguish a particular stage which is predominant over other stages in a particular time. Thus the reduction in RGR at period of 70 - 80 days after transplanting (in 2002) was mainly due to that plants (at this time) were at flowering and early fruit set stages which both are considered as developmental rather than growth stages. Moreover, the reduction in RGR, in period of 70 – 80 days, was severe in plants irrigated with saline water than that in plants irrigated with non-saline water, such reduction was high as 11.5% in this particular period while the percentage of reduction were only 9.1 and 7.1% in periods of 60-70 and 80-90 days, respectively. In similar study Scholberg and Locascio (1999) indicated that growth decreased linearly with increased salinity during flowering.

The increase in RGR at 80-90 days after transplanting (Table 6) may due to the increasing in weight of the developing new fruits.

The reduction percentage in RGR resulted from irrigation tomato plants with the highest level of saline water (compared to those irrigated with non- saline water) were 6.7, 11.0 and 7.5% when drip irrigation used, while counterpart reduction were 9.5, 11.5 and 8.5% when furrow irrigation used in periods of 60-70, 70-80 and 80-90 days after transplanting respectively. The reduction in RGR was severe in all stages in plants irrigated by furrows than those irrigated by drippers and at period of 70-80 days after transplanting, in particular, which was coincident to flowering and fruit set stage.

Table 5. Effect of irrigation method and salinity level on dry matter partitioning to different plant organs and top root ratio (top was not involved fruit weight) of tomato determined in 3 sampling dates in 2001 season.

Sampling date	Irrigation method	Saliniy level (dS/m)	Partitioning of dry matter %				Top root ratio
			roots	stems	leaves	fruits	
60 days after transplanting	Drip	0.55	4.41	39.70	42.82	13.90	18.73
		4.50	4.68	41.90	42.03	11.22	18.64
20 days after treatment	Furrow	0.55	4.25	39.88	45.67	9.78	18.07
		4.50	4.70	42.08	44.30	8.92	18.39
initiation	L.S.D. at 0.05		0.42	NS	2.67	1.3	NS
75 days after transplanting	Drip	0.55	3.40	28.18	28.95	39.49	16.83
		4.50	3.35	29.81	27.64	39.22	17.17
35 days after treatment	Furrow	0.55	4.13	31.33	33.19	31.35	15.63
		4.50	3.85	33.55	31.90	30.70	17.00
initiation	L.S.D. at 0.05		NS	2.4	1.3	2.6	1.1
90 days after transplanting	Drip	0.55	2.30	20.69	22.30	54.72	19.10
		4.50	2.26	22.73	21.90	53.14	19.31
50 days after treatment	Furrow	0.55	2.50	21.03	22.21	54.26	17.26
		4.50	2.50	22.80	21.40	53.32	17.60
initiation	L.S.D. at 0.05		NS	1.2	NS	NS	1.4

Leaf mineral and dry matter content

Irrigation with saline water (4.5 dS/m) increased the concentration of chloride and sodium in the leaves regardless of the irrigation method and water management strategy used (Table 7). Mg content also increased by salinity. Similar findings were also reported by El-Sawaby and Amer (1977) and Ullah et al. (1994), regarding the accumulation of Na, Cl and Mg in salinised plants. However, Ca, K, P and N all were decreased with using saline water. Therefore, the decrease in growth of salinised plants was associated with an increase in the concentrations of sodium and chloride, which are toxic, (Pasternak and Demalach, 1995; El-Sawaby and Amer, 1977) and with ionic imbalance (Cusido et al., 1987), in plant leaves, a normal consequence of salinisation.

Table 6. Effect of irrigation method, water management strategy, salinity level on relative growth rate during periods in days after transplanting.

Variables		Salinity levels (dS/m)	RGR g/day 2001		2002		
Periods in days after transplanting			60 - 75	75 - 90	60 – 70	70 - 80	80 - 90
Drip	Cyclic	0.55	0.043	0.038	0.045	0.026	0.053
		2.00	0.042	0.037	0.045	0.025	0.050
		3.00	0.041	0.036	0.043	0.024	0.050
		4.50	0.041	0.035	0.042	0.023	0.049
		Mean	0.041	0.036	0.044	0.024	0.051
	Blended	0.55	0.043	0.038	0.045	0.026	0.053
		2.00	0.043	0.038	0.046	0.026	0.052
		3.00	0.042	0.036	0.044	0.026	0.051
		4.50	0.041	0.035	0.043	0.023	0.050
		Mean	0.043	0.037	0.045	0.026	0.052
	Average		0.042	0.037	0.044	0.025	0.051
Furrow	Cyclic	0.55	0.035	0.046	0.042	0.026	0.059
		2.00	0.034	0.045	0.040	0.025	0.056
		3.00	0.034	0.045	0.039	0.024	0.054
		4.50	0.033	0.040	0.038	0.023	0.054
		Mean	0.034	0.044	0.040	0.024	0.055
	Blended	0.55	0.036	0.045	0.042	0.026	0.060
		2.00	0.038	0.046	0.043	0.027	0.057
		3.00	0.035	0.044	0.041	0.025	0.056
		4.50	0.034	0.041	0.038	0.023	0.054
		Mean	0.036	0.045	0.041	0.025	0.056
	Average		0.035	0.045	0.040	0.025	0.056
Irrigation water manage-ment	Cyclic	2.00	0.038	0.041	0.043	0.025	0.053
	Cyclic	3.00	0.038	0.041	0.041	0.024	0.052
	Average (B)		0.038	0.041	0.042	0.025	0.053
	Blended	2.00	0.041	0.042	0.045	0.027	0.055
	Blended	3.00	0.039	0.041	0.043	0.026	0.054
	Average (B)		0.040	0.042	0.044	0.027	0.055
Salinity levels	Average (C)	0.55	0.039	0.042	0.044	0.026	0.056
		2.0	0.039	0.042	0.044	0.026	0.055
		3.0	0.038	0.041	0.042	0.025	0.053
		4.5	0.037	0.038	0.040	0.023	0.052
LSD for averages of irrigation methods (A) at P = 0.05			0.003	0.004	0.003	NS	.004
LSD for averages of water management (B) at P = 0.05			0.001	0.001	0.001	0.0008	0.001
LSD for averages of salinity levels (C) at P = 0.05			0.002	0.002	0.002	0.001	0.003
LSD for interaction (AxBxC) at P = 0.05			0.004	0.005	0.004	0.002	0.005

Na, Cl and Mg content were lower in leaves of plants irrigated by drippers than those of plants irrigated by furrows (Table 7). Moreover, both Na, Cl contents were higher in leaves of plants irrigated by cyclic management than those irrigated by blended management regardless method of irrigation used (Table 7).

Dry matter percentage in tomato leaves increased by irrigation with saline water (Table 7). But it seems that this increase in dry matter content is due to a reduction in leaf water content rather than to dry matter accumulation. Same conclusion was also reported by Ehret and Ho (1986) in similar study.

Salinity distribution in root zone

Figure 1 illustrated that salinity was at the highest concentration at the surface layer of the soil i.e., 15 cm depth (at all horizontal sites i.e., from 0-60 cm from irrigation source, with one exception; the drip irrigation with saline water) and at 30 cm from irrigation source, at the four soil depths. In general, salinity concentration reduced with soil depth. Also, in plots irrigated with saline water, salinity concentration at 90 cm depth and at 60 cm from irrigation water (horizontally) were almost the same for both salinity levels and both irrigation systems.

Table 7. Effect of irrigation method, water management strategy and salinity level on some mineral and dry matter contents (interaction values) in tomato leaf at 95 days from transplanting in 2000 season.

Irrigation Method	Water Management Strategies	Salinity Levels (dS/m)	Ca %	Cl %	K %	Na %	P %	N %	Mg %	Dry matter content (%)
		0.55	3.300	1.082	1.326	0.475	0.256	2.52	0.484	17.6
	Cyclic	2.00	3.300	1.420	1.184	0.481	0.206	2.59	0.555	18.6
		3.00	3.100	1.535	1.158	0.482	0.196	2.42	0.573	21.6
Drip		4.50	2.500	2.430	0.996	0.493	0.182	1.82	0.654	23.8
		0.55	3.500	1.077	1.326	0.465	0.256	2.52	0.484	17.3
	Mixed	2.00	3.540	1.420	1.533	0.475	0.249	2.60	0.541	21.8
		3.00	3.050	1.598	1.449	0.472	0.256	2.44	0.559	21.75
		4.50	2.600	2.370	1.202	0.496	0.185	1.75	0.654	23.3
		0.55	3.500	1.410	0.993	0.475	0.240	2.66	0.736	19.5
	Cyclic	2.00	3.300	1.775	0.912	0.502	0.209	2.63	0.821	20.2
		3.00	2.600	2.310	0.912	0.515	0.182	2.38	0.820	20.6
Furrow		4.50	3.000	2.612	0.912	0.554	0.169	2.33	0.892	22.5
		0.55	3.500	1.241	0.993	0.474	0.240	2.75	0.741	19.3
	Mixed	2.00	3.700	1.415	0.912	0.495	0.249	2.52	0.750	19.8
		3.00	3.600	1.598	1.077	0.502	0.236	2.38	0.798	20.7
		4.50	3.000	2.485	0.870	0.565	0.188	2.24	0.853	22.6
L.S.D. at P (0.05)			0.43	0.25	0.08	0.02	0.01	0.32	0.03	3.12

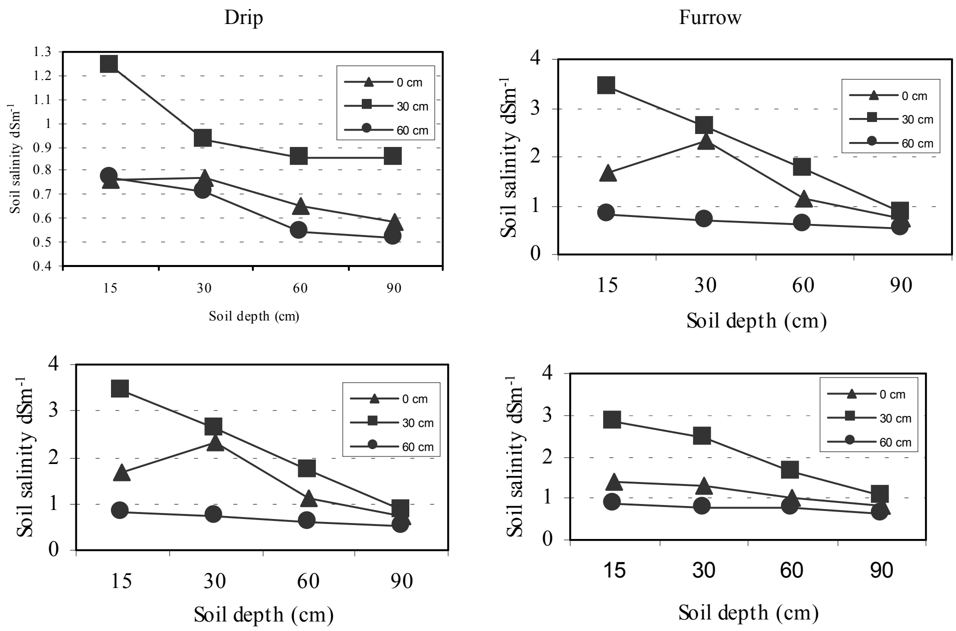

Figure 1. Vertical (from 15 to 90 cm soil depth) and horizontal (at 0, 30 and 60 cm from irrigation source) salinity distribution in soil profile either irrigated by drip (left) or furrow (right) methods with either fresh i.e. non saline (upper) or saline i.e. highest salinity level (lower) waters, at 29/6/2001 (before irrigation).

The depth of 80% of root weight (maximum root density) for tomato plants in this experiment was between 15 to 21 cm, (data not shown). At this particular area (15-21 cm) beneath the irrigation source, as in the case of drip irrigation, salinity concentration was low (1.7 dS/m) (Figure 1 left and lower). However, salinity of this volume of soil (with maximum root density) in plots irrigated by furrows (Figure 1 right and lower) was much higher (2.9 dS/m) as the site of the plants were not beneath the irrigation source but at 30 cm horizontally from irrigation source where more salts accumulated. This is likely to be a contributory factor in the poorer performance of furrow irrigated plants in comparison with those that were irrigated with drippers.

Similar findings regarding salt movement and accumulation in drip irrigated plots were also obtained by Bakr et al. (1979) and West et al. (1979) and in furrow irrigated plots (Bakr et al., 1979) when irrigated with saline water.

In plots received fresh water, salts did not accumulate at 30 cm beneath the drippers (Figure 1 left and upper), as in plots received saline water.

Yield and yield components

Increasing salinity of irrigation water (regardless of irrigation method or water management) gradually decreased tomato yield. But reduction in yield was significant only at 3 dS/m and above (Table 8). This means that salinity of irrigation water up to 2 dS/m could not reduce tomato yield significantly. However, irrigated tomato with saline water at 3 dS/m level reduced its yield by 15.0%, but using 4.5 dS/m dramatically reduced yield i.e., 31% (average of the two seasons). Drip irrigation had a favorable effect on tomato yield compared to furrow irrigation (Table 8), under both saline and non-saline conditions. In similar studies Singandhupe et al. (2003) and Hebbar et al. (2004) found that yield of drip irrigation was higher than that of furrow irrigation.

Table 8. Effect of irrigation method, water management strategy, salinity level and their interaction on total fruit yield in 2001 and 2002 seasons.

Variables		Salinity levels (dS/m)	Total yield t. / Faddan*	
			2001	2002
Drip	Cyclic	0.55	34.58	29.77
		2.00	31.31	25.70
		3.00	29.17	24.36
		4.50	24.41	19.51
		Mean	29.87	24.84
	Blended	0.55	35.15	29.77
		2.00	36.25	28.00
		3.00	32.68	26.87
		4.50	24.27	19.51
		Mean	32.09	26.04
	Average		30.98	25.44
Furrow	Cyclic	0.55	31.15	25.11
		2.00	25.55	21.37
		3.00	24.50	19.32
		4.50	21.65	17.73
		Mean	25.71	20.88
	Blended	0.55	31.80	25.11
		2.00	32.29	24.83
		3.00	28.98	22.59
		4.50	21.92	17.73
		Mean	28.45	22.57
	Average		27.23	21.72
Irrigation water manege-ment	Cyclic	2.00	28.43	23.54
	Cyclic	3.00	26.84	21.84
		Mean	27.63	22.69
	Blended	2.00	34.27	26.42
	Blended	3.00	30.83	24.73
		Mean	32.55	25.28
Salinity levels	Average C	0.55	33.17	27.44
		2.0	31.35	24.98
		3.0	28.83	23.30
		4.5	23.06	18.62
LSD for averages of irrigation methods (A) at P = 0.05			2.67	2.24
LSD for averages of water management (B) at P = 0.05			3.18	2.41
LSD for averages of salinity levels(C) at P = 0.05			3.72	3.25
LSD for interaction (AxBxC) at P = 0.05			8.43	7.44

* Faddan = 4200 m^2

Also using blended water management gave better results in terms of producing higher yields under salinity treatments than did cyclic water management (Table 8). In this respect, Adams and Ho (1989) found that applied high saline water alternatively with low saline water at day and night cycles reduced fruit size and number (and hence fruit yield) more than a constant level of salinity (the average of the fluctuating salinities).

Table 9. Effect of the interaction between irrigation methods, water management strategy and salinity level on some fruit quality characters at harvesting.

Irrigation methods	Water Manage-ment Strategies	Salinity levels (dS/m)	Ave. fruit wt.	Fruit No./ plant	Fruit TSS (%)	Ave. fruit wt.	Fruit No. / plant	Fruit TSS (%)
			2000 season			2001 season		
Drip	Cyclic	0.55	104.7	29.5	4.08	107.8	27.3	4.6
		2.00	99.6	27.1	4.52	101.3	26.5	5.1
		3.00	97.3	25.9	4.90	99.2	25.2	5.2
		4.50	95.6	24.8	4.67	96.4	21.7	5.3
	Blended	0.55	104.7	29.5	4.03	107.8	27.9	4.6
		2.00	104.8	30.5	4.08	107.9	28.9	4.9
		3.00	96.9	30.4	4.17	104.5	26.8	5.1
		4.50	95.5	25.6	4.58	97.8	21.5	5.3
Furrow	Cyclic	0.55	112.2	25.1	3.72	115.2	23.1	4.9
		2.00	100.3	24.2	3.85	103.3	20.6	5.1
		3.00	98.4	24.2	4.53	99.6	20.3	5.3
		4.50	98.6	22.5	4.70	97.4	18.9	5.5
	Blended	0.55	113.6	25.3	3.90	116.8	23.5	4.9
		2.00	114.6	25.8	3.83	116.3	23.8	5.0
		3.00	109.0	25.7	4.02	111.4	22.3	5.1
		4.50	100.5	22.7	4.52	98.4	19.1	5.5
L.S.D at P = 0.05			6.74	2.03	0.56	5.4	2.2	0.54

In treatment of the combination between drip irrigation, blended water management and salinity up to 3 dS/m, the yield was reduced only by 8% (average of the two seasons) which was not significantly different than that obtained by using non-saline water.

Although, some workers (Mizrahi, 1982; Martinez et al., 1987; Cuartero and Fernandez Munoz, 1999) indicated that the reduction in tomato yield by salinity is caused mainly by reduction in the average of fruit weight, the results of this study revealed significant reduction in both fruit number and weight by using 4.5 dS/m. These findings support those found by, Alam *et al*. (1989), Alarcon et al. (1994), del Amor et al. (2001) and Malash et al. (2005) who indicated that both fruit number and weight decreased with salinity, even with low and moderate salinity levels. Then, it could conclude that flowering and fruit set may be varied in their response to salinity according to the environmental conditions.

Although, furrow irrigation enhanced fruit weight than did drip irrigation, fruit number of plants drip irrigated was more than those of furrow irrigated plants (Table 9).

Again using blended water management resulted in producing larger and more fruits than those produced by plants received cyclic water management (Table 9). This probably due to the fluctuation in soil conductivity when irrigation with fresh followed by saline waters in salinity treatments as reported by Malash et al. (in press).

Fruit TSS. however, increased with increasing salinity of irrigation water, whatever were irrigation method and water management (Table 9).

Water Use Efficiency

Drip irrigation increased water use efficiency (WUE) relative to furrow irrigation (Table 10). Moreover, increasing salinity in irrigation water up to 3 dS/m significantly increased WUE than that obtained by using non-saline water (particularly with drip irrigation).

The higher WUE obtained by drip irrigation, comparing to furrow irrigation, was expected as plants in the former system irrigated with lower amount of water than that used in the later, meanwhile yield was higher with drip irrigation. These findings support those of Yohannes and Tadesse (1998) who reported that higher yields and WUE has been attributed to drip irrigation than furrow irrigation. Also, irrigation with saline water reduces plant water uptake, which reduces amount of water applied, meanwhile yield was not dramatically reduced by low salinity levels up to 3 dS/m. This may explain why low and moderate salinity enhanced WUE.

Table 10. Effect of irrigation method, water management strategy and salinity level on water use efficiency (interaction values) in 2002 season.

Salinity level (dS/m) and water management*	Water use efficiency Kg/m^3	
	Drip	Furrow
0.55	55.64	19.41
2.0 (C)	66.70	19.51
3.0 (C)	64.23	20.77
2.0 (B)	77.29	19.71
3.0 (B)	71.47	21.83
4.5	54.76	20.15
L.S.D. at P= 0.05	4.6	

*(C): Cyclic, (B): Blended

Conclusion

Salinity of irrigation water restricted plant growth, and decreased fruit yield by reduced both fruit weight and number. The results of this study recommend the use of drip irrigation in general and under saline condition in particular, as the fruit yield and yield per unit of water used were higher than when using furrow irrigation. In addition to maintaining ideal water levels, drip irrigation reduced salinity accumulation in root zone, which in turn reduced Na, Cl and Mg uptake and minimize their content in leaves, in such a way reduces salinity hazards in plants drip irrigated than those furrow irrigated. Although, the cost of a drip system/unit area irrigated is higher than that of a furrow system when calculated for a single year, the advantage of drip system lies when costs are calculated for larger areas over longer times (Abouzaid, 2002). Blending irrigation water provides a better yield than alternating fresh and saline water, at least when low and moderate salinity levels were used. The results showed that continuous constant level of salinity used as irrigation water (blended) gave better results in terms of vigour growth and high yield than did applied saline water followed by fresh water (cyclic) and so on which resulted in fluctuating soil conductivity.

Acknowledgements

We would like to acknowledge the financial support of the EU-funded contract "SALTMED" and all colleagues on that program, especially Prof. T. J. Flowers and Dr. R. Ragab also we wish to thank Dr. A. Hewidy for following up the fertilization and pest management programs, throughout the four years of the experiments**.**

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